RESEARCH ARTICLE

Design and Analysis of Alternative Coating Bio-Material for Gas Turbine Engine Blade for High Temperature Aerospace Application

Prithviraj Kandekar[1], Akshay Acharya[1], Basangouda Patil[1], Aakash Chatta[1], Arun Y Patil*[1], Shridhar Mathad [2]

[1]School of Mechanical Engineering,K.L.E.Technological University, Hubballi, Karnataka, India
[2]Department of Engineering Physics, K.L.E Institute of Technology, Hubballi 580027, India

ABSTRACT: Airways play an important role in transportation in the new era of transport. The engine part must withstand a lot of heat and force for such long travel hours. Engine compressor blades are one such component, in which blades undergo a temperature change. This change in temperature causes the material to wear out as time passes. In the modern age of transport, airways play a major role in transportation. For such long travel hours, the engine component must endure a lot of heat and force. One such part is engine compressor blades. Here, the blades undergo a change in temperature. As time passes, this change in temperature causes the material to wear out.

KEYWORDS: Coating material, Bio-Material, Gas Turbine Engine Blade, Aerospace Application

https://doi.org/10.29294/IJASE.9.4.2023.3106-3114

INTRODUCTION

Air transport is one of the most common ways to fly long distances within a short period of time. The bulk of air transport consists of commercial aircraft and one of the essential tasks is aerial transport and patrol, also in the defence sector. The engine is the key part that forms the foundation of these airplanes. The engine is the key part that forms the foundation of these air-planes [1]. The architecture and mechanism of the engines are completely distinct and complex as ordinary vehicle engines [2]. There has been continuous research and research in this area for many years now to develop new materials and designs to reduce the raw materials used and achieve high performance [1].The standard engine consists of the compressor, the combustion system, the turbine, and the control turbine of the gas manufacturer [3]. Here, the compressor mechanism where the air is drawn in and let out is primarily considered here. Here, the blades undergo a temperature change. This temperature shift [4] causes the material on the blade to wear out as time passes. When the device is left unchecked, it poses a threat. There have been several investigations and studies to resolve this. Temperature changes can cause thermal expansion and contraction of materials, which can lead to mechanical stresses and strains within the material. Over time, these stresses can cause the material to degrade, resulting in wear and tear on the blade. This is especially true for materials with different coefficients of thermal expansion, which can experience differential expansion and contraction that can lead to cracking, warping, and other forms of damage.

Biomaterials have gained significant attention in recent years due to their ability to offer unique properties such as biocompatibility, biodegradability, and non-toxicity, among others. One application of biomaterials is as a coating agent for engine blades in the aviation industry, where their exceptional properties can offer several benefits. The potential of biomaterials such as silk fibroin, chitosan, and hydroxyapatite as coating agents for engine blades, with improved corrosion resistance, wear resistance, and aerodynamic performance being the main benefits. Silk fibroin coatings improved the high-temperature oxidation resistance of the blades and reduced the surface roughness, thereby enhancing their aerodynamic performance [5]. The chitosan-

*Corresponding Author: patilarun7@gmail.com
Received: 15.02.2023 **Accepted:** 17.04.2023 **Published on**: 22.05.2023

based coating exhibits on the wear resistance and corrosion protection of turbine blades and showed that the chitosan coating improved the wear resistance of the blades and reduced their corrosion rate, making it a promising candidate for turbine blade coatings. Turbine blades made of nickel-based alloys are mainly used in high pressure turbines in the aviation industry and in power plants [6]. The researchers found that the hydroxyapatite coatings improved the corrosion resistance of the blades and reduced the surface roughness, resulting in improved aerodynamic performance [7]. The graphene oxide as a coating material for engine components, the researchers found that the graphene oxide coating improved the wear resistance, thermal stability, and anti-corrosion properties of the engine components [8].

The main reason for the use of limpet teeth is one such material to have 100 times stronger tensile strength than steel and has more than 10 times stronger than spider web. This study suggests an alternative coating material that is capable of handling loads over time and lasts longer than the materials commonly used. Bio-material [9-10] is one significant field of research. Bio-Material has proved to be one of the materials that can survive longer in this state over the years. The structures of the composite materials show it to be one of the best materials that can be used for coating.

1.1 Compressor Blade

This constitutes of a Solid Disc on which the blades are mounted on. These are made up of high-grade material and are precise in the construction. This all makes up a Compressor Blade [11] as seen in Figure 1.

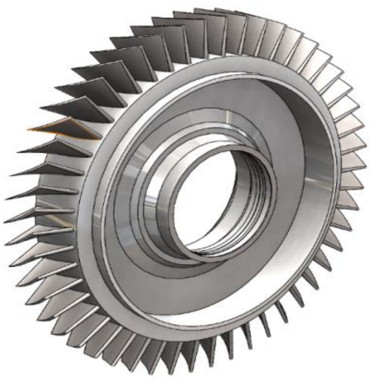

Figure 1.Blade of Gas Turbine

2. Problem statement

Design and analysis of alternative coating bio-material for Gas turbine engine blade for aerospace application

3. Methodology

A step-by-step procedure was carried out from design to simulation using tools like SOLIDWORKS2016 and ANSYS2020 R2 version [12]. Software used is ANSYS WORKBENCH. The entire analysis initiated with static structural analysis, thermal analysis, fatigue analysis etc.

3.1 Design of Compressor Blade

The initial step involved in the material selection is by collecting all the necessary material properties which are stated in table 1.

Table 1 Material Properties

Properties	Ti4Al6V	Nimonic 90	Limpet
Density	4429 kg/m^3	8180 kg/m^3	800 kg/m^3
Youngs modulus	110 GPa	213 GPa	110 GPa
Poisson ratio	0.31	0.3	2.1

3.1.1 3D modelling

Based on the dimensions provided by the Aerospace Institute, the model was built in SOLIDWORKS 2016 using features like extrude, extrude cut and revolve. Also, the model was cleaned up by removing the parts and features which were not needed for the analysis to minimize the computational time. The final model for the analysis is given in the Figure 2. This model consists of various numbers of blades and it is mounted on the High-Pressure shaft.

3.2 Determining load and boundary conditions

- Mesh control = 25 mm
- Face mesh = 10 mm
- Refinement on Blades
- Ambient Temperature = 250°C
- Cylindrical support
- Film Coefficient: $10W/m^2K$
- Inlet pressure: 1.01Bar

4. Simulation study

The succeeding approach was followed to solve the problem and the same was checked for both the setups during the analysis using the Pure penalty approach [13-16], the model obtained is shown in Figure 3(a) is the geometry obtained for the Initial setup, Figure 3(b) is the geometry obtained for the proposed setup which has surface coating as shown in the figure.

The analysis software here used is ANSYS 2020 R2 version.

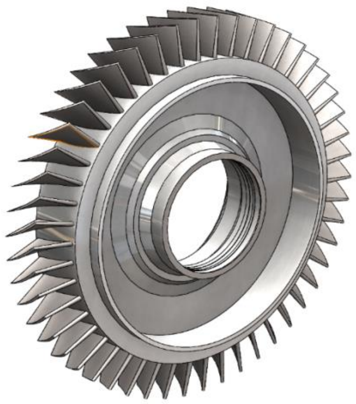

Figure 2.SOLIDWORKS model of Compressor Blade

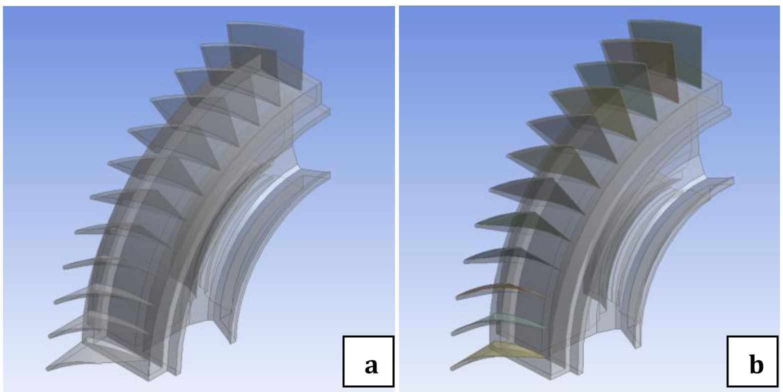

Figure 3. Geometry obtained in ANSYS2020 R2 workbench (a) Without Coating, (b)With Coating

4.1 Type of Analysis

As we are not considering then on-linearity behavior, we are going forward with Modal [17], Random Vibration [18] and Harmonic response [19] as our major form of analysis as shown in Figure 4. Also Fatigue analysis [20] is been carried for the proposed model.

4.2 Contact generation

The springs are in no separation connection [21] with the blades is bonded as seen in Figure 5.

4.3 Mesh generation

A Tetragonal mesh [22] was obtained for the model as shown below in Figure 6. Based on the element size, the following data were obtained for this case of meshing as seen in Table 2.

Table 2 Statistics for the model

Maximum element size (mm)	Tetragonal	
	Elements	Nodes
10	50052	100085

Prithviraj Kandekar et al.,

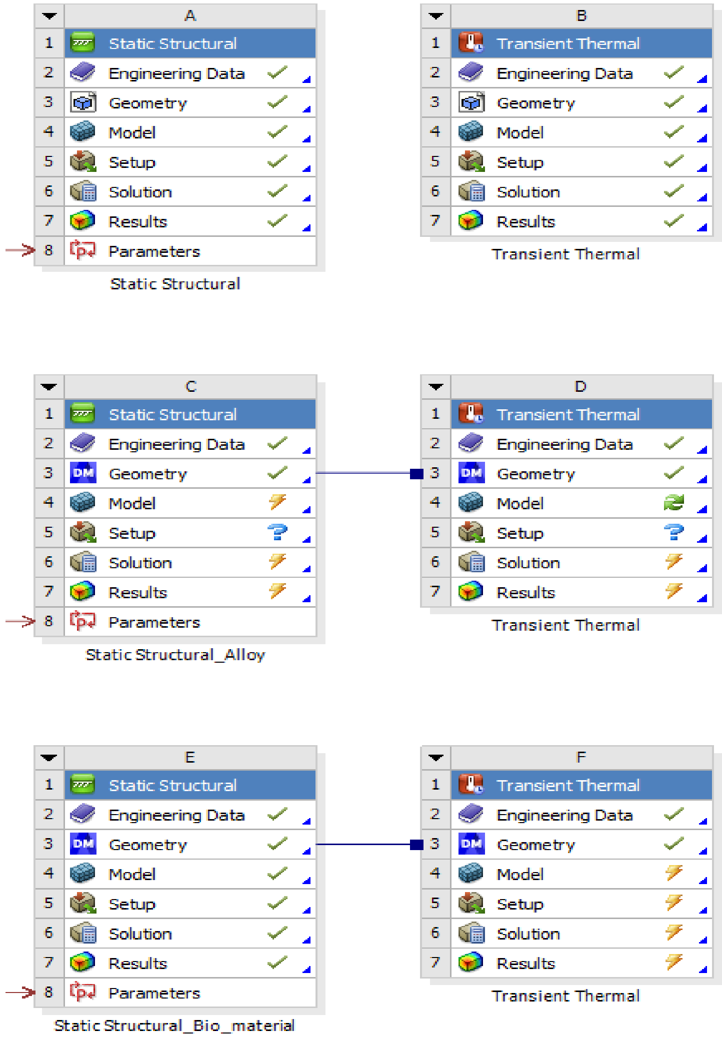

Figure 4: Analysis setup inANSYS

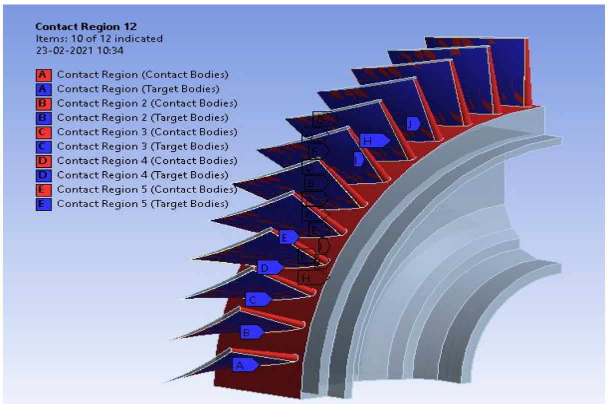

Figure 5: Connections generated in ANSYS workbench

It is evident from the above statistics that a higher number of nodes and elements is obtained at finer element sizes (10 mm) The results obtained are more reliable when the number of nodes and elements is significantly higher. On the other hand, when the number of nodes is more, it takes Additional computational power.

To improve and check the convergence of the results, two methods were used

a) H -type: This technique involves altering the global size of the element set during the meshing process either with raising or lowering the size of an element without changing the type of mesh being used in simulations. Which results may not always converge [23].

b) P-type: This approach focuses on the form of mesh used in the analysis, keeping the size of the element constant. Which means the order of the elements is changed. Higher-order means more reliable results, but it needs more computational time, noticeably [24].

The following types have been used to infer about convergence and precision, hence the convergence method of type H is used throughout the analysis.

4.4 Pre-processing for simulation

a) Static analysis

As illustrated in the Figure 7 static analysis is an important method of analysis of the mechanical characteristics. We can determine the characteristics of compressor bladeand the stress and deformation parameters. That way, it is an important basis for under the dynamic load structure design. We created in the SOLIDWORKS, a three-dimensional model for chassis assembly. This provides a theoretical basis for compressor blade structure optimization. The figure 7 shows pressure and cylindrical support for the compressor blade.

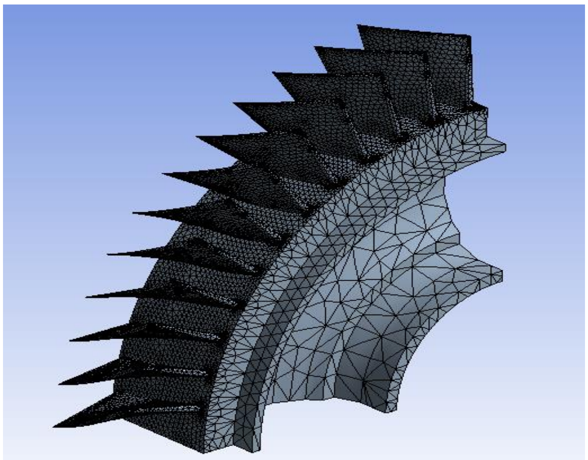

Figure 6Generated mesh

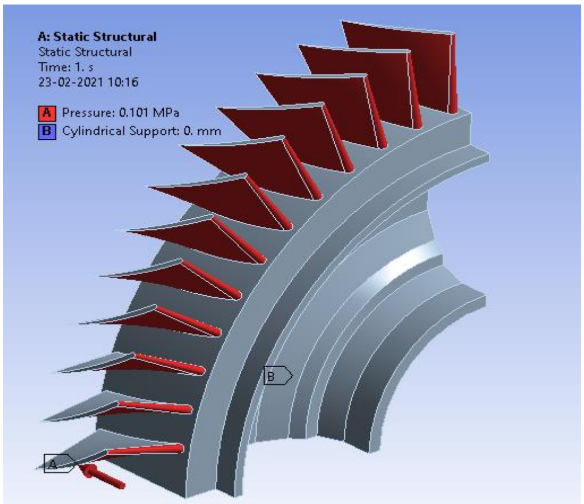

Figure 7Constraints for static structural analysis

b) Thermal analysis

Thermal analysis is a general term describing a method used when a material is heated or cooled to analyze the time and temperature at which physical changes occur. Each approach is characterized by the types of physical changes that are evaluated. The faces selected for the analysis is shown in Figure 8.

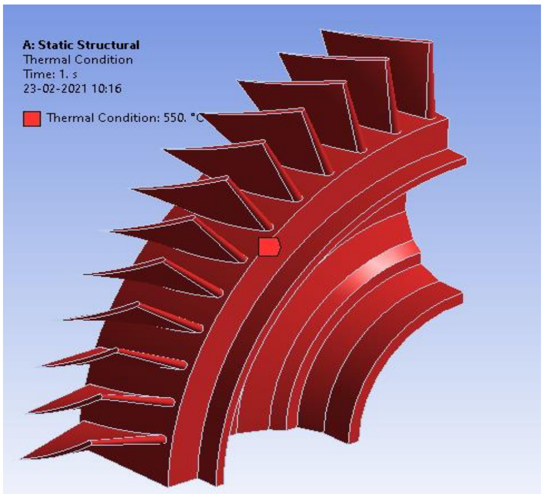

Figure 8 Temperature constraint applied for the Compressor Blade

4. RESULTS AND DISCUSSION

The changes seen in the Figure 9-11 for stress [25], strain [26], deformation [27], heat flux [28] is noticeable and the heat flux is decreased by 77.7%, 55.55% as compared with in Ti4Al6V and Nimonic 90 axis respectively.

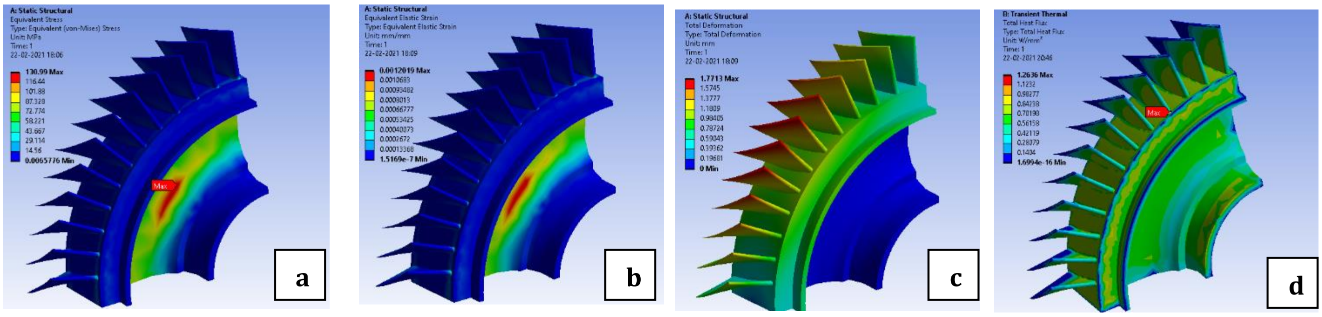

Figure 9 a) Stress b) Strain c) Deformation d) Heat flux (Standard gas turbine)

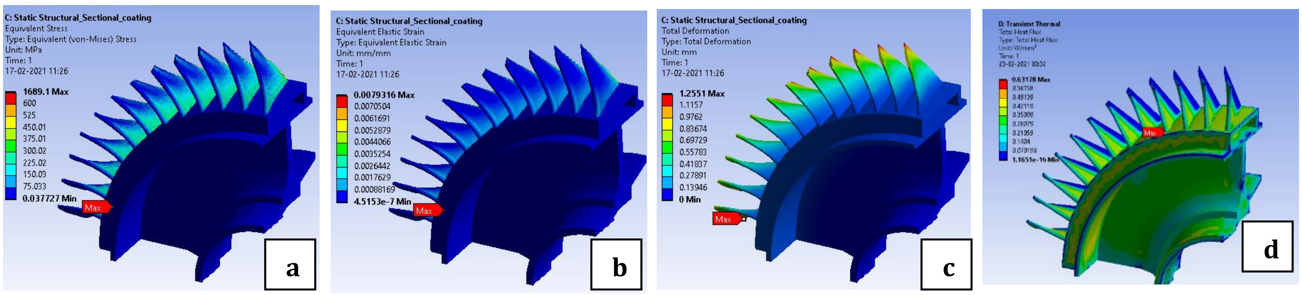

Figure 10 a) Stress b) Strain c) Deformation d) Heat flux (Alloy)

Prithviraj Kandekar et al.,

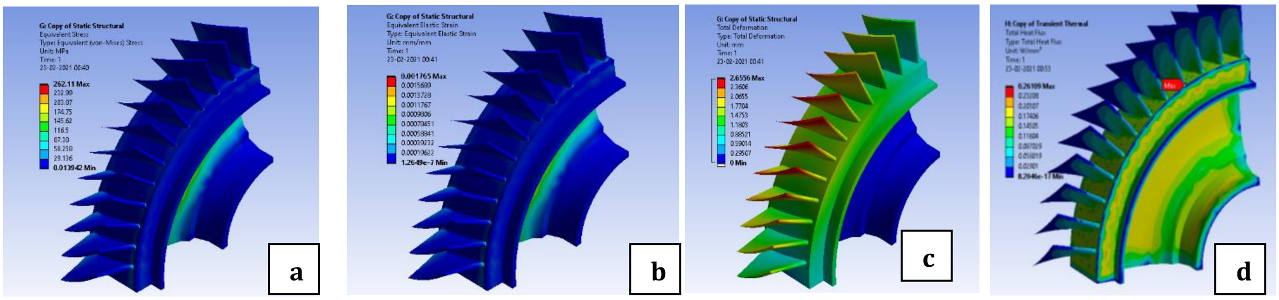

Figure 11 a) Stress b) Strain c) Deformation d) Heat flux (Bio-material)

Table3. Physical quantities of random vibration for Initial Setup (Without AVP)

Type	Stress (MPa)	Deformation (mm)	Strain	Heat Flux W/mm^2
Standard (Ti4Al6V)	131	1.7	0.0012	1.26
Alloy (Nimonic 90)	650	1.25	0.0078	0.63
Bio-Material (Limpet teeth)	262	2.65	0.0017	0.28

a) Static Analysis

After running this analysis, we found out that the stress on the edge of the Bio-material coating is exceeds its yield point but the average stress obtained falls under the yield point which is desired output for our setup. Also, strain and deformation are obtained.

b) Thermal Analysis

Parameters like heat flux and final temperature are obtained after thermal transient analysis. We observe that limpet teeth have the least heat flux and acts like a ceramic material.

6. CONCLUSION

The analysis was carried out on the compressor blade of Gas turbine engine with and without the surface coating to check for stress, deformation, strain, and heat flux. We could interpret that the stress has notice-ability increased compared to the standard aerospace alloy, as well as the deformation has increased, though the heat flux has decreased. The proposed set-up could be used in a real-time scenario after the fatigue life analysis. Limpet teeth are one of the strongest naturally available bio materials, but behave as a ceramic and hence lower cooling rate. The project is kept open ended as more Research is needed on Limpet teeth to get necessary properties. From the task, along with the results, it is possible to add surface coating to the present setup at a very marginal cost.

REFERENCES

[1] Razak, A.M.Y. 2013. Gas turbine performance modelling, analysis and optimization. In Woodhead Publishing Series in Energy, Modern Gas Turbine Systems (pp. 423-514).

[2] Razak, A.M.Y. 2007. Simulating the effects of engine component deterioration on engine performance. Industrial Gas Turbines (pp. 489-523). Woodhead Publishing.

[3] Vaferi, K., Vajdi, M., Nekahi, S., Nekahi, S., Moghanlou, F., ShahediAsl, M., Mohammadi, M. 2021. Thermo-mechanical simulation of ultrahigh temperature ceramic composites as alternative materials for gas turbine stator blades. Ceramics International, 47(1), 567-580.

[4] Shao, Q., Lyu, B., Yuan, J., Wang, X., Ke, M., Zhao, P. 2021. Shear thickening polishing of the concave surface of high-temperature nickel-based alloy turbine blade. Journal of Materials Research and Technology, 11, 72-84.

[5] K. Vijayakumar, 2021. Silk fibroin coatings for improved oxidation resistance and

surface roughness reduction of gas turbine blades, Materials Today Communications, 27, 102352

[6] Ma,K., 2019. Effect of hydroxyapatite coatings on the corrosion behavior and surface roughness of nickel-based superalloy turbine blades, Journal of Materials Engineering and Performance, 28(9) 5648-5655

[7] Ray, S., 2015. Applications of graphene and graphene-oxide based nanomaterials. William Andrew.

[8] Frost-Jensen, J., Nicolai, Leon, M., Jr., Arash D, Neil A. Williams, Søren, F.,, Alessio, S., Irene G., and Homayoun, H.. 2021. Nanoengineered Graphene-Reinforced Coating for Leading Edge Protection of Wind Turbine Blades, Coatings 11, no. 9: 1104.

[9] Reshmy, R., Philip, E., Madhavan, A., Sindhu, R., Pugazhendhi, A., Binod, P., Sirohi, R., Awasthi, M.K., Tarafdar, A., Pandey, A. 2021. Advanced biomaterials for sustainable applications in the food industry: Updates and challenges. Environmental Pollution, 283, 117071.

[10] Du, P., Wu, Z., Li, K., Xiang, T., Xie, G. 2021. Porous Ti-based bulk metallic glass orthopedic biomaterial with high strength and low Young's modulus produced by one step SPS. Journal of Materials Research and Technology, 13, July–August 251-259,

[11] Poojari, Y.M., Annigeri, K.S., Bandekar, N., Annigeri, K.U., Badiger, V., Patil, A.Y., Billur, S., Kotturshettar, B.B. 2020. An alternative coating material for gas turbine blade for aerospace applications. Journal of Physics: Conference Series, 1706, 012183.

[12] Akshay, K., Hombalmath, M., Mathad, M., Rane, S., Patil, A., Kotturshettar, B. (2020). Design and analysis of engine mount for biodegradable and non-biodegradable damping materials, J. Phys.: Conf. Ser. 1706 012182,

[13] Mudigoudra, S., Ragi, K., Kadennavar, M., Danashetty, N., Sajjanar, P., Patil, A. Y., M., S., K., Suresh, H., Kotturshettar, B. B. 2020. Reduction effect of electromagnetic radiation emitted from mobile phones on human head using electromagnetic shielding materials. Journal of Physics: Conference Series, 1706(1), 012184.

[14] Dhaduti, S., Ganachari, S. R., Patil, A. Y. 2020. Prediction of injection molding parameters for symmetric spur gear. Journal of Molecular Modeling, Springer Nature, 26(11):302.

[15] Poornakanta, H., Kadam, K., Pawar, D., Medar, K., Makandar, I., Patil, A. Y., Kotturshettar, B. B. 2018. Optimization of sluice gate under fatigue life subjected for forced vibration by fluid flow. Journal of Mechanical Engineering. 68(3), 129-142.

[16] Patil, A. Y., Banapurmath, N. R., Jayachandra, S. Y., Kotturshettar, B. B., Shettar, A. S., Basavaraj, G. D., Keshavamurthy, R., Yunus-Khan, T. M., Mathad, S. 2019. Experimental and simulation studies on waste vegetable peels as bio-composite fillers for light duty applications. Arabian Journal of Engineering Science, Springer-Nature publications. 44, pages 7895–7907.

[17] Patil, A. Y., Banapurmath, N. R., Shivangi, U. S. 2020. Feasibility study of Epoxy coated Poly Lactic Acid as a sustainable replacement for River sand. Journal of Cleaner Production, Elsevier publications, 267.

[18] Yashasvi, D.N., Badkar, J., Kalburgi, J., Koppalkar, K. 2020. Synthesis and characterization of advanced materials. IOP Conf. Ser.: Mater. Sci. Eng., 872, 012016.

[19] Kandekar, P., Acharaya, A., Chatta, A., Kamat, A. 2020. Sustainable materials for engineering applications. IOP Conf. Ser.: Mater. Sci. Eng., 872, 012076.

[20] Patil, V.S., Banoo, F., Kurahatti, R.V., Patil, A.Y., Raju, G.U., Soudagar, M.E.M., Kumar, R., Ahamed, C.S. 2021. A study of sound pressure level (SPL) inside the truck cabin for new acoustic materials: An experimental and FEA approach. Alexandria Engineering Journal, 60, 5949–5976,

[21] Patil, A.Y., Naik, A., Vakani, B., Kundu, R., Banapurmath, N.R., Roseline, M., Krishnapillai, L. 2021. Next generation material for dental teeth and denture base material: Limpet Teeth (LT) as an alternative reinforcement in Polymethylmethacrylate (PMMA). Journal

of Nano- and Electronic Physics, 5(4) 04001.

[22] Kohli, A., Ishwar, S., Charan, M.J., Adarsha, C.M., Patil, A.Y., Kotturshettar, B.B. 2020. Design and simulation study of pineapple leaf reinforced fiber glass as an alternative material for prosthetic limb. IOP Conf. Ser.: Mater. Sci. Eng., 872, 012118.

[23] Yavagal, P. S., Kulkarni, P. A., Patil, N. M., Salimath, N. S., Patil, A. Y., Savadi, R. S., Kotturshettar, B. B. 2020. Cleaner production of edible straw as replacement for thermoset plastic. Materials Today Proceedings, 32(3), 2020, 492-497,

[24] Totla, S. K., Pillai, A. M., Chetan, M., Warad, C., Patil, A. Y., Kotturshettar, B. B. 2020. Analysis of Helmet with Coconut Shell as the Outer Layer. Materials Today Proceedings, 32(3) 365-373.

[25] Kohli, A., Annika, H., Karthik, B., Pavan, P. K., Lohit, P. A., Sarwad, P. B., Patil, A. Y., &Kotturshettar, B. B. 2020. Design and Simulation study of fire-resistant biodegradable shoe. Journal of Physics: Conference Series, 1706(1), 012185.

[26] Kohli, A., Ghalagi, V., Divate, M., Manakatti, C., Karigar, M. I., Poojar, D., Pandugol, T., Patil, A. Y., Billur, S., Kotturshettar, B. B. 2020. Investigation on pineapple fiber reinforced polymer composites. Journal of Physics: Conference Series, 1706(1), 012186.

[27] Kumar, A., Rane, S. S., Hombalmath, M., Mathad, M., Patil, A. Y., Kotturshettar, B. B. 2020. Design and analysis of engine mount for biodegradable and non-biodegradable damping materials. Journal of Physics: Conference Series, 1706(1), 012182.

[28] Patil, A. Y., Umbrajkar, H. N., Basavaraj, G. D., Kodancha, K. G., Chalageri, G. R. 2018. Influence of Bio-degradable Natural Fiber Embedded in Polymer Matrix. Materials Today, 5, 7532–7540.